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Asymmetries of total arterial supply of cerebral hemispheres do not exist

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Asymmetries of total arterial supply of cerebral hemispheres do not exist

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Abstract

Background: Total blood supply to an organ, or its part, is proportional to its function. The aim of this project was to investigate whether there is a lateralisation of total functions of cerebral hemispheres by determining differences in the arterial blood supply to left and right cerebral hemispheres.

Methods: Diameters of right and left anterior, middle and posterior cerebral arteries were measured at specific sites and cross-sectional areas calculated in 203 adult brains (51 donated and dissected brain specimens and 152 cerebral arterial Computed Tomography Angiography and Magnetic Resonance Angiography images).

Findings: The sample size was large enough to provide a power of detecting as significant differences of 4%, but neither of the average cross-sectional areas of right anterior, middle and posterior cerebral arteries were significantly different from those of the anterior, middle and posterior cerebral arteries of the left side. Furthermore, combined areas of the three right cerebral arteries were not significantly different from combined areas of the left three arteries. This clearly indicates that the blood supply into the right cerebral hemisphere is not different

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from that of the left cerebral hemisphere. Therefore, there is no total functional lateralisation between the two cerebral hemispheres.

Conclusion: Brain lateralisation, frequently discussed in the literature, does not deferentially influence the total activity levels of cerebral hemispheres.

Keywords: Anatomy, Neuroscience

1. Introduction

Specialisation of neural functions of the brain to one hemisphere rather than the other hemisphere [1] has been referred to as lateralisation of a brain function. Pierre Paul Broca [2] (1861−1865) proposed the idea that the left hemisphere is functionally lateralised for language processes and many others expanded the idea of lateralization [3, 4, 5] of cerebral hemispheres regarding speech and language processes, and the handedness [4]. The concept of lateralization of some specific functions seems to hold true statistically, however, many individuals do not conform to this pattern. Music perception, rhythms and synthesis of pitches [2, 6, 7] are examples of functions that are not specialized to a cerebral hemisphere. Benton and colleagues [8] found that both cerebral hemispheres are involved in facial perception and the memory. A behavioural functional Magnetic Resonance Imaging (MRI) study done on 12 right handed individuals suggested that the right frontal cortex mostly and sometimes bilateral frontal cortices [9] were involved in memory retrieval procedure.

It has been suggested that functional asymmetries are reflected in structural asymmetries between the two hemispheres of the brain. Structural symmetry and asymmetry of the brain, in relation to the function and the relationship of the structural asymmetry to lateralisation of the functions have been investigated extensively [10]. The structural asymmetry in right and left hemispheres has been discussed based on the depth of the central sulcus, larger anteriorly protruding right frontal lobe and the longer and posteriorly protruded left occipital lobe [10]. However, most of the findings related to the lateralization are ambiguous and have no definitive results [3, 11, 12, 13, 14, 15, 16].

A book [16] on brain hemispheric lateralization has highlighted the cortical structural asymmetries, but the measured regions and the technique used to take measurements were not clear [16, 17]. This book has mentioned the handedness and behavioural functional lateralization in relation to the size of corpus callosum. However, the role of tracts of corpus callosum is to increase the interhemispheric connectivity and ensure involvement of cortical components of both cerebral hemispheres in specific functions [5]. A recent investigation of Magnetic Resonance Imaging (MRI) scans of brains obtained from more than 17000 healthy individuals did not show bilateral variation in cerebral cortex thickness of most of the 39 regions of the cortex of the two hemispheres [18].

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Furthermore, in cerebral regions where variations in cortical thickness between the hemispheres were evident, variations of the surface areas were also seen. That is, if the cortical thickness of one region was lesser than that of the same region of the contralateral hemisphere, the surface area of the thinner region was greater than that of thicker region of the contralateral hemisphere and vice versa [18]. This indicates that the volume of the cortical tissues of the brain regions of the two hemispheres remained similar. Therefore, this large study did not show structural evidence for variations in cortical function between hemispheres. A study, done in 54 adult donated brains, found that neither total dimensions of cerebral hemispheres (width, length and height), nor sizes of their major anatomical features (length of main sulci or height and length of lobes) showed any significant right-left differences [19]. The asymmetric patterns of dural venous sinuses result in the entire cerebral hemispheres to move anteriorly or posteriorly producing apparently asymmetric locations of occipital and frontal poles [20]. The arrangements and positions of posterior and lateral cerebral dural venous sinuses were studied in 58 brains and concluded that entire cerebral hemispheres moved in accordance with dural venous sinus asymmetries anteriorly or posteriorly producing asymmetric "petalia" [20]. Handedness has been considered as a common manifestation of cerebral lateralisation, and yet handedness can be easily changed by training [21, 22, 23, 24].

Cross-sectional areas of nutrient foramina in mammalian long bones correlate with actual blood flow into the bone and its metabolic rate [25]. Arterial blood supply of a cortical area of the cerebral hemisphere has been shown to be directly proportional to the magnitude of its function [26]. Cross sectional area of an artery is directly proportional [27, 28] to the amount of blood flowing through the artery. It follows that cross-sectional areas of the arteries supplying each cerebral hemisphere are good indicators of functions in the hemispheres. Therefore, comparing sizes of arteries supplying right and left hemispheres should provide information about lateralisation of functions of areas they supply. Blood supply to each cerebral hemisphere comes from only three branches of the cerebral basal arterial network (CBAN) comprising the vertebrobasilar component and the anterior arterial circle of the brain [29] (circulus arteriosus cerebri). Therefore, although cerebral hemispheres are complex entities, it is easy to measure their total blood supply by adding together areas of the three cerebral arteries: anterior, middle and posterior. This study determined the cross-sectional areas of arteries supplying each cerebral hemisphere of the human brain with the aim of testing whether one hemisphere is functionally dominant over the other by determining differences in their arterial blood supply.

2. Materials & methods

2.1. Data section

Arterial diameters were determined on Magnetic Resonance Angiography (MRA) and Computed Tomography Angiography (CTA) digital recordings obtained from

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152 live adult patients at the Royal Adelaide Hospital documented in the Carestream database and in 51 adult brains dissected out from human bodies. Patients' documented in the Carestream database had given written permission to university clinicians and academics to use the data for research purposes after obtaining ethics approval. Patient's identities have not been recorded and documented. The dissected bodies were donated to Adelaide Medical School, the University of Adelaide for research. All measurements were taken after obtaining approval from the University of Adelaide ethics committee (Ethics approval No. H2014-176).

2.2. Data collection/measurement

Diameters of anterior, middle and posterior cerebral arteries were measured bilaterally in dissected brains and MRA and CTA scans [30] at the sites indicated in Figs. 1, 2, and 3. In donated brains, external diameters of the arteries were measured using a digital Vernier caliper. In digital images of MRA and CTA scans obtained from live patients; the internal diameters of the three arteries were measured using image J software programme [30, 31]. External diameters of the arteries in donated brains and internal diameters in MRA and CTA digital scans are the only diameters that could be measured accurately. The digital Vernier calipers have been commonly

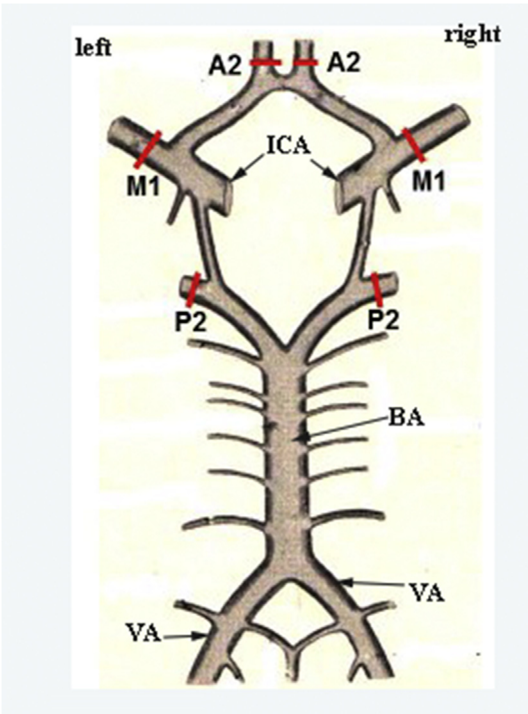

Fig. 1. Schematic diagram. Red lines perpendicular to the long axis of the vessels indicate measurement sites, PCA = posterior cerebral artery, ACA = anterior cerebral artery, MCA = middle cerebral artery, rt = right, lft = left, A2 = the most proximal portion of second part ACA, P2 = the most proximal portion of the second part of PCA, M1 = the most proximal portion of the first part of MCA.

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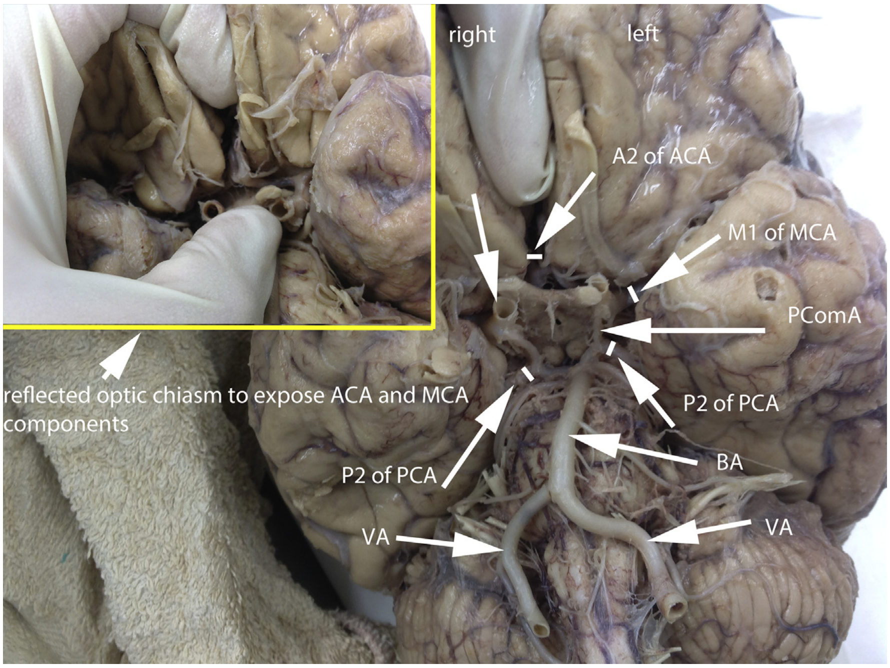

Fig. 2. Basal view of the brain, white lines without arrows showing the measurement sites of vessel diameter, PCA = posterior cerebral artery, ACA = anterior cerebral artery, MCA = middle cerebral artery, rt = right, lft = left, A2 = the most proximal portion of second part ACA, P2 = the most proximal portion of the second part of PCA, M1 = the most proximal portion of the first part of MCA, BA = basilar artery, ICA = internal carotid artery, VA = vertebral artery.

used [32, 33, 34, 35, 36] to measure the arterial diameter in cadaveric brains. Magnetic Resonance Angiography and CTA have been used for morphometry of different components of brain and they seem to be more accurate [30] than measurements taken physically on brains. The accuracy and the reliability of the measurements were determined by repeating the procedure in 15 cadavers, and 10 MRA and CTA digital scans. Technical errors of measurement (TEM) and reliability coefficients (r) are presented in Table 1. This project is designed to observe the differences in the blood supply between the left and right cerebral hemispheres of each brain comparing the left and right arteries of the same individuals, thus the arterial measurements were not subdivided into groups according to the method of measurement nor according to the age and sex.

2.3. Statistical analysis

A priori power analysis with a power 0·80 and two-tailed probability 0·05 indicated that to detect in a paired t-test a difference of about 10% in mean arterial diameters (Cohen's effect size of 0·5), the minimum sample size is 33. Both samples exceeded this size. A sample size of 128 was required to detect 5% mean difference with the same assumed parameters. This sample size was exceeded by our scan data

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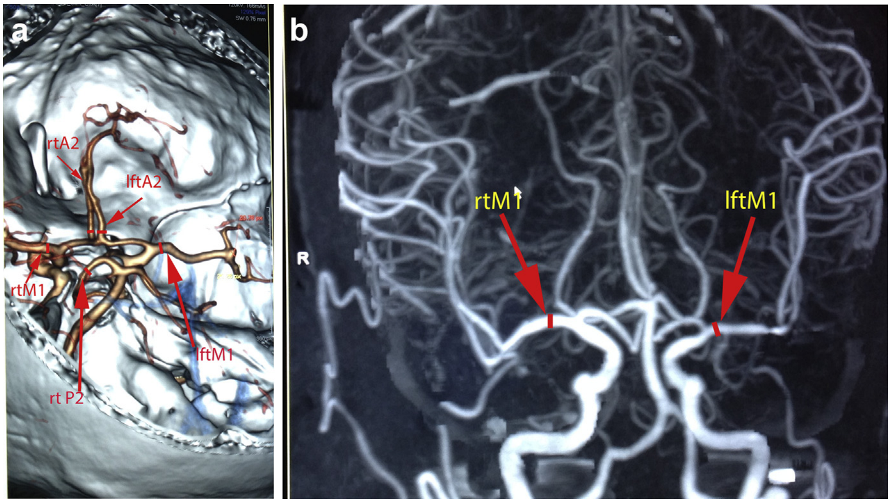

Fig. 3. a and b: Figure showing the sites of arterial diameter measurement in reconstructive cerebral arterial Computed Tomography Angiography (CTA) and Magnetic Resonance Angiography (MRA), rt = right, lft = left, green lines showing the measurement sites of vessel diameters, A2 = the most proximal portion of second part of anterior cerebral artery and M1 = the most proximal portion of the first part of middle cerebral artery.

(N = 152) and by joined samples (N = 203). A sample of 198 was needed to detect 4% size differences, that is about 0·3 mm^2 in the size of the single artery or 0·7 mm^2 in the total size of arteries. Our total sample size (n = 203) exceeded the calculated 198.

Table 1. Accuracy and reliability of the measurements in Computed Tomography Angiography (CTA) and Magnetic Resonance Angiography (MRA) scans and cadaveric brains. The coefficients of variation of the measurements are presented: TEM = Technical errors of measurement, PCA = posterior cerebral artery, ACA = anterior cerebral artery, MCA = middle cerebral artery, Rt = right, Lft = left, A2 = the most proximal portion of second part ACA, P2 = the most proximal portion of the second part of PCA, M1 = the most proximal portion of the first part of MCA.

Arterial components measured	Measurements in cadaveric brains (n = 15)		Measurements in scans (n = 10)	
	TEM	Reliability (r)	TEM	Reliability (r)
Rt P2	0.13	0.97	0.02	0.99
Lft P2	0.1	0.97	0.04	0.98
Rt M1	0.11	0.97	0.03	0.99
Lft M1	0.07	0.97	0.02	0.99
Rt A2	0.07	0.97	0.07	0.96
Lft A2	0.21	0.97	0.04	0.98

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Descriptive statistics and paired t-test were used to compare the calculated cross-sectional areas of the arteries supplying the right and left cerebral hemispheres. Probability (P) values less than 0·05 were taken as significant. Statistical analyses were conducted using SPSS v 25. Linear regressions of right on left arterial sizes were run to observe any deviation of residuals to the right or left (Fig. 4). Paired t-tests were applied to each artery and to the total size of arteries. We also counted how many brains had a particular artery larger on the right and how many on the left. These numbers were compared using chi-squared sign test. The same comparison was performed for the sum of arterial sizes dominating on the right or on the left (Tables 2 and 3).

3. Results

The tests were conducted separately and combinedly for data obtained from prosected brains and CTA and MRA images. Mean cross sectional areas of right and left, anterior, middle and posterior cerebral arteries of donated brains and CTA and MRA scans are presented in Table 2. The average combined cross-sectional area of right anterior, middle and posterior cerebral arteries supplying the right cerebral hemisphere of dissected brains (18.8 mm^2) did not differ significantly ($t = 0.6$) from the relevant value for the left hemisphere (19.0 mm^2). In CTA and MRA study, the average combined cross-sectional area of three right cerebral

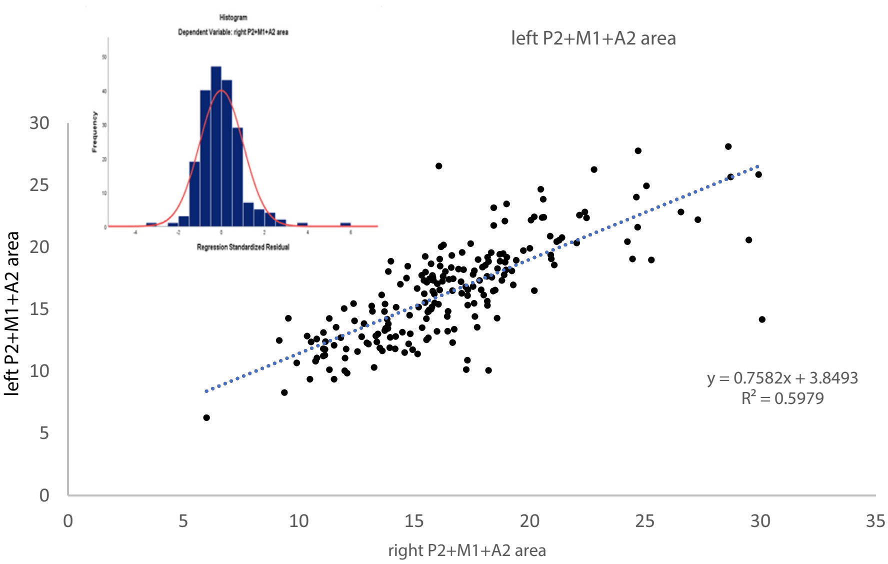

Fig. 4. Sum total of cross-sectional areas (mm^2) of left anterior, posterior and middle cerebral arteries regressed on sum total of cross-sectional areas of right anterior, posterior and middle cerebral arteries. Arterial data taken from cadaveric brains and Computed Tomography Angiography and Magnetic Resonance Angiography ($n = 203$). Right- scattergram and left- distribution of residuals around the regression line. Observe symmetrical distribution of residuals around zero. This distribution does not differ significantly from the normal distribution.

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Table 2. Means and standard deviations (mm^2), and paired samples t-test results comparing right and left anterior, middle and posterior cerebral arterial cross sectional areas determined from dissected donated **brains, Computed Tomography Angiography (CTA) and Magnetic Resonance Angiography (MRA) data, N = 203,** PCA = posterior cerebral artery, ACA = anterior cerebral artery, MCA = middle cerebral artery, A2 = the most proximal portion of second part ACA, P2 = the most proximal portion of the second part of PCA, M1 = the most proximal portion of the first part of MCA, ns = not significant, ACA A2a = cross sectional area measured at the most proximal portion of second part of ACA, MCA M1a = cross sectional area measured at the most proximal portion of the first part of MCA and PCA P2a = cross sectional area measured at the most proximal portion of the second part of PCA.

Items	cadaveric paired sample test, N = 51				CTA and MRA scan- paired sample test, N = 152				Total (cadaveric and scans) paired sample test, N = 203			
	Right	Left	Paired t-test	sign.	Right	Left	Paired t-test	sign.	Right	Left	Paired t-test	sign.
	Mean (Std.Dev)	Mean (Std.Dev)	t- value		Mean (Std.Dev)	Mean (Std.Dev)	t- value		Mean (Std.Dev)	Mean (Std.Dev)	t- value	
ACA A2a	5.6 *1.9*	5.5 *1.6*	0.3	ns	4.5 *1.5*	4.4 *1.4*	1.8	ns	4.8 *1.7*	4.6 *1.5*	1.2	ns
MCA M1a	7.8 *2.0*	8.3 *2.3*	−1.7	ns	6.7 *2.1*	6.7 *2.1*	0.3	ns	7.0 *2.1*	7.1 *2.2*	−0.8	ns
PCA P2a	5.4 *1.4*	5.3 *1.2*	0.5	ns	4.7 *1.6*	4.5 *1.4*	1.3	ns	4.9 *1.6*	4.7 *1.4*	1.4	ns
ACA A2a + MCA M1a + PCA P2a	18.8 *3.6*	19.0 *3.5*	−0.6	ns	15.9 *4.0*	15.6 *3.8*	1.8	ns	16.6 *4.1*	16.5 *4.0*	0.9	ns

arteries was 15.9 mm^2 while on the left it was 15.6 mm^2 ($t = 1.8$). Dissected brains indicated that the arteries were larger on the left and the MRA and CTA scans data showed that the arteries were larger on the right side. These differences were random and fell within the insignificant range.

Table 3. Cross-sectional area measured on left and right cerebral arteries from cadaveric and Computed Tomography Angiography and Magnetic Resonance Angiography scans data and their comparison using formula; $\chi^2 = (\text{left} - \text{right})^2/(\text{left} + \text{right})$, n = 203, lft = left, rt = right, P2a = posterior cerebral artery second part (P2 proximal segment) cross sectional area, A2a = anterior cerebral artery second part (A2 segment) proximal cross-sectional area, M1a = middle cerebral artery first part (M1 segment) proximal cross-sectional area in mm^2, ns = not significant.

Arterial area	Arterial cross-sectional area	Larger on:		χ^2
	Equal	Left	Right	
A2a	5	93	105	ns
M1a	7	100	96	ns
P2a	9	93	101	ns

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In the combined cadaveric and the scanned samples, the average difference between the total right and left areas of arteries was 0.09 mm^2. It was not significant ($t = 0.5$). The results for the left and right differences of individual arteries- anterior, middle and posterior, were small and all statistically insignificant. The residuals of regressions of right cerebral arterial cross-sectional areas on corresponding arterial cross-sectional areas of the left were normally symmetrically distributed around a mode of zero (Fig. 4). The number of the brains showing larger arteries on the right was similar to that on the left, statistically these numbers were indistinguishable because the test, $\chi^2 = (\text{left} - \text{right})^2/(\text{left} + \text{right})$ did not provide the significant results (Table 3).

4. Discussion

Current study shows that there are no right and left differences in cross sectional areas of arteries supplying the cerebral hemispheres (Tables 2 and 3). These clearly indicate that in the left cerebral hemisphere, there are no additional functional areas in the territories supplied by the anterior, middle and posterior cerebral arteries compared to the same territories of the right hemisphere. Lateralisation of one or more functions to a cerebral hemisphere is expected to associate with increase in the volume of cortical tissues of the respective area/areas (i.e. thickness or surface area or both of the specific region/regions) compared to the contralateral hemisphere. This will result in increased need for blood supply, thus the cross-sectional area of an artery supplying the region, and the total cross-sectional areas of arteries supplying a cerebral hemisphere should increase. Dominance of one hemisphere should lead to the asymmetry of the size of arteries. Where there is no laterization of the function, blood flow to each hemisphere would be the same.

Another interpretation is also possible: if the lateralization of the brain functions were such that exactly half of all functions were located in the left and another half in the right hemisphere, then the blood flow, and the cross-sectional areas of arteries to both hemispheres would be the same. Some of the human functions such as language, handedness, logical reasoning have been generally accepted to be located in the left hemisphere [3, 11, 14, 37, 38, 39] in most people and the left occipital petalia present in most human beings were cited as an indication of the enlargement of the left hemisphere.

The handedness and behavioural functional lateralization have been studied in relation to the size of corpus callosum. However, the role of corpus callosum tracts is to increase the interhemispheric connectivity and ensure the need of having bilateral cortical components to perform some specific functions together and support the functional relationship between the adjacent components of the cerebral hemispheres [5].

Recent studies on lateralization have revealed that some functions are mastered particularly well by one hemisphere [15, 16], while other functions might be mastered by

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the other hemisphere so that the total functional output of each hemisphere is similar. In other words, the idea of hemispheric specialization may apply to specific function, but not to all functions [4]. Any tissue and organ in the body, including a part of the brain performing particular function, requires more blood flow. If, however, function occurs intermittently for short periods, the amount of blood flow may increase but the flow is not large enough to cause permanent change to the arterial structures. Brain works continuously, and especially during wakefulness performs number of functions simultaneously, so that both hemispheres require constant flow of blood. It may be that each hemisphere performs different functions, but the sum total is the same as in the contralateral hemisphere, or that many functions use both hemispheres communicating via corpus callosum, anterior and posterior commissures. Results of the current study cannot distinguish between these two possibilities.

Since each cerebral hemisphere is entirely supplied by the three arteries-anterior cerebral artery (ACA), posterior cerebral artery (PCA) and middle cerebral artery (MCA) [27, 28, 40], thus the total cross-sectional areas of these arteries are a good indicator of the function of a cerebral hemisphere. The total size of a cerebral hemisphere is the size of the cerebral cortex and its subcortical connections. Therefore, if a cortex of a given hemisphere is larger due to its functional dominance, the entire hemisphere should be larger.

In another study, dimensions of right cerebral hemispheres of 54 donated brains were compared with those of the left hemispheres and no significant size differences between the two hemispheres were found [19]. Furthermore, the arrangements of asymmetric posterior and lateral cerebral dural venous sinuses (in 58 brains) were found to be correlated with the petalial patterns. Larger volume of blood in dural venous sinuses in the posterior aspect of the right of the cranial cavity might move the entire right cerebral hemisphere anteriorly [20]. This produces larger occipital extent of the left hemisphere, and larger anterior extent of the right hemisphere, a pattern found in approximately 60% of people [41]. This difference in appearance does not indicate there is real difference in size [20].The cortical thicknesses of 39 functional areas of one cerebral hemisphere has been compared with those of the same 39 functional areas of the other hemisphere in MRI scans obtained from 17,000 healthy individuals [18]. No significant differences between the two cerebral hemispheres were found. These three studies mentioned in in this paragraph, investigated different indicators of cerebral lateralization and found no differences between two cerebral hemispheres.

Most of the findings related to the lateralization are ambiguous and have no definitive results, structural asymmetry exists only statistically, there are no specific criteria to prove it. Current study examined the arterial cross-sectional areas supplying the cerebral hemispheres and the findings show small and uniformly insignificant differences between left and right cerebral arterial cross-sectional areas. Functional

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predominance and different cognitive functions between the two hemispheres have been reported [16], however the size of the arteries supplying the two hemispheres in this study, does not indicate greater function of one hemisphere compared to the other hemisphere.

5. Conclusion

Blood supply from anterior, posterior and middle cerebral arteries to the right and left cerebral hemispheres is the same. Since the blood supply is proportional to the function, we suggest that there is no asymmetry in total functions of cerebral hemispheres.

Declarations

Author contribution statement

Arjun Burlakoti, Jaliya Kumaratilake, Maciej Henneberg: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Jamie Taylor: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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